Water Quality
Supplement 5.14

Water: The Big Picture

We do not just drink water, we are water. Water constitutes 50 to 90 percent of the weight of all living organisms. It is one of the most abundant and important substances on Earth. Water sustains plant and animal life, plays a key role in the formation of weather, helps to shape the surface of the planet through erosion and other processes, and covers roughly 70% of the Earth's surface.

A casual glance at Earth might make you think that the earth has enough water to meet the needs of living things forever. After all, Earth is known as the "Water Planet," because oceans cover more than 70% of its surface. In fact, about 97% of the Earth's water is found in the oceans. But living things cannot use most of the ocean water because it contains salt.

Fresh water makes up about 3% of the Earth's water. But most of this fresh water cannot be used because it is locked up in ice, mainly in ice caps near the North and South poles and in glaciers. In fact, only 15% of the Earth's fresh water is available for use by living things. This very small percentage represents the earth's total available supply of fresh water. With such a limited supply, you might wonder why the Earth does not run out of fresh water. It does not because the supply or fresh water is continuously being renewed by means of the hydrologic cycle.

Water continually circulates between the Earth's surface and its atmosphere in what is called the hydrologic or water cycle. Responding to heat from the sun and other influences, water from the oceans, rivers, lakes, soils and vegetation evaporates into the air and becomes water vapor. The water vapor rises into the atmosphere, cools and turns into liquid water or ice, forming clouds. When the water droplets or ice crystals get large enough, they fall back to the surface as rain or snow. Once on the ground, water does one of three things: some of it filters into the soil and is either absorbed by plants or percolates downward to groundwater reservoirs; some runs off into streams and rivers and eventually into the oceans; some evaporates.

All water is part of the same system. The total annual water loss from the surface of the planet equals the Earth's total annual precipitation. Changing any part of the system, such as the amount of vegetation in a region or land use, affects the rest of the system.

Water participates in many important chemical reactions, and most substances are soluble in water. Due to its effectiveness as a solvent, truly pure water rarely occurs in nature. Water carries many natural and human-introduced impurities as it travels through the hydrologic cycle. These impurities give each form of water its distinctive chemical makeup, or *quality.* Rain and snow capture small dust particles or *aerosols* from the air, and sunlight causes emissions from the burning of gasoline and other fossil fuels to react with water to form sulfuric and nitric acids. These pollutants return to

Earth as *acid rain or snow.* The acids in the water slowly dissolve rocks, placing *dissolved* solids in water. Small but visible pieces of the rocks and soils also enter the water, resulting in *suspended* solids and making some waters turbid. When water percolates into the ground, it is in very close contact with rocks and more minerals dissolve into the water. These impurities, dissolved or suspended in water, determine its quality.

In this investigation, students will measure the following key indicators of water quality.

Water Temperature
Water temperature is largely determined by the amount of solar energy absorbed by the water and the surrounding soils and air. More solar heating leads to higher water temperatures. Water that has been used in manufacturing and discharged into a water body may also increase water temperature. Water evaporating from the surface can lower the temperature of the water, but only for a very thin layer at the surface. We need to measure water temperature to understand the patterns of change over the year, because the temperature of a water body strongly influences the amount and diversity of its aquatic life. Lakes that are relatively cold and have little plant life in winter, bloom in the spring and summer when water temperatures rise and the nutrient-rich bottom waters mix with the upper waters. One also finds periods of mixing in the fall. Because of the mixing and the warmer water temperatures, the spring overturn is followed by a period of rapid growth of microscopic aquatic plants and animals. Many fish and other aquatic animals also spawn at this time of year, when the temperatures rise and food is abundant. Shallow lakes are an exception to this cycle, as they mix throughout the year. One concern is that warm water can be fatal for sensitive species, such as trout or salmon, which require cold, oxygen-rich conditions.

Dissolved Oxygen
Water is a molecule made of two hydrogen atoms and one oxygen atom – hence, H_2O. However, mixed in with the water molecules of any body of water are molecules of oxygen gas (O_2) that have dissolved in the water. Dissolved oxygen is a natural impurity in water. Aquatic animals, such as fish and the zooplankton they feed on, do not breathe the oxygen in water molecules; they breathe the oxygen molecules dissolved throughout the water. Without sufficient levels of dissolved oxygen in the water, aquatic life suffocates. Dissolved oxygen levels below 3mg/L are stressful to most aquatic organisms.

In the atmosphere, roughly one out of every five molecules is oxygen; in water, about one to ten molecules in every million molecules are oxygen. Vigorous mixing of air and water, such as in turbulent streams, increases the amount of oxygen dissolved in water, as does photosynthesis by aquatic plants. Fish, zooplankton and the bacteria that decompose organic materials consume oxygen. Organic materials, such as dead plant and animal matter enter streams naturally in water draining from forests and grass or crop lands. Another source of organic matter is outfall from sewage treatment plants. Whatever the source, we tend to find low dissolved oxygen levels, well under half the saturated value, in slow moving streams near sources of organic matter. In addition, warm water holds less oxygen than cold water, so critical periods for fish and zooplankton tend to occur in summer. For example, at 25°C, dissolved oxygen solubility is 8.3mg/L, whereas at 4°C the solubility is 13.1mg/L .

pH

pH is a measure of the acid content of water. The pH of water influences most of its chemical processes. Pure water with no impurities (and not in contact with air) has a pH of 7. Water with impurities will have a pH of 7 when its acid and base content are exactly equal and balance each other out. At pH values below 7 we have excess acid, and at pH levels above 7 we have excess base in the water.

The pH scale is different from the concentration scale we use for other impurities. It is logarithmic, which means that a one-unit change in pH represents a factor of ten change in the acid content of the water. Thus water with a pH of 3 has ten times the acid content of water with a pH of 4, which in turn has ten times the acid content of water with a pH of 5.

Natural, unpolluted rain has a pH between 5 and 6, so even rain water from the least polluted place on Earth has some natural acidity. This natural acidity is the result of carbon dioxide from the air dissolving in the rain drops. Distilled water, which is in equilibrium with the air, will have this same pH. The most acidic rain has a pH of about 4, though urban fogs with pH of less than 2 have been measured. Most lakes and streams have pHs in the range of 6.5 to 8.5. One can find waters that are naturally more acidic in areas with certain types of minerals in the soil, (e.g., sulfides). Mining activity can also release acid-causing minerals into a stream. Naturally basic waters are found typically in areas where the soil contains minerals such as calcite or limestone.

The pH of a water body has a strong influence on what can live in it. Salamanders, frogs and other amphibious life are particularly sensitive to low pH. Most insects, amphibians and fish are absent in water bodies with pH below 4.

Electrical Conductivity

Pure water is a poor conductor of electricity. It is the impurities in water, such as dissolved salts, that enable water to conduct electricity. A good indicator of the total level of impurities in fresh water is its electrical conductivity – how well water passes electrical current. The more impurities in water, the greater its electrical conductivity.

For most agricultural and municipal uses, water should have a total dissolved solid content well below 1000 to 1200 parts impurity per million parts water by weight (ppm), or an electrical conductivity (ability to pass electrical current) below about 1500 to 1800 microSiemens/cm (Note that 1ppm = 1mg/L). Above these levels, one can expect damage to sensitive crops. For household use, water is preferred with a total dissolved-solids content below about 500ppm, or below a conductivity of about 750 microSiemens/cm. The residues left on “clean” dishes just out of the automatic dishwasher are a product of dissolved solids in water. Manufacturing, especially of electronics, requires impurity-free water. Pure, alpine snow from remote areas has a conductivity of about 5 to 30 microSiemens/cm.

Alkalinity

Alkalinity is the measure of a water's resistance to the lowering of pH when acids are added to the water. Acid additions generally come from rain or snow, though soil sources are also important in some areas. Alkalinity is generated as water dissolves rocks containing calcium carbonate, such as calcite and limestone. When a lake or stream has too little alkalinity, typically below about 100mg/L, a large influx of acids from a big rainfall or rapid snowmelt could (at least temporarily) consume all of the alkalinity and thus drop the pH of the water to levels harmful for amphibians, fish or zooplankton. Lakes and streams in areas with little soil, such as in mountainous areas, are often low in alkalinity. These water bodies can be particularly sensitive in the spring during periods of rapid snowmelt. Because pollutants tend to wash out of a snowpack during the first part of snowmelt, a higher influx of acidic pollutants is often encountered in the spring, which is also a critical time for the growth of aquatic life.

Nitrate

Plants in both fresh water and saline waters require major nutrients for growth -- carbon, nitrogen and phosphorus. In fact, most plants tend to use these three nutrients in the same proportion, and cannot grow if one is in short supply. Carbon is relatively abundant in the air as carbon dioxide, which dissolves in water, so a lack of either nitrogen or phosphorus generally limits the growth of aquatic plants. In some cases, trace nutrients such as iron can also be limiting, as can sunlight. Nitrogen exists in water bodies in numerous forms -- dissolved molecular nitrogen (N_2), organic compounds, ammonium (NH_4+), nitrite (NO_2^-) and nitrate (NO_3^-). Of these, nitrate is usually the most important. Nitrite is usually only present in suboxic waters (low dissolved oxygen levels). The nitrate form of nitrogen, found in natural waters, comes naturally from the atmosphere in rain, snow, fog or dry deposition, or from the decay of organic material in soil and sediments. It can also come from agricultural runoff. Farmers add nitrogen fertilizer to crops, some of which drains out of the soil when it rains.

When an excess amount of a limiting nutrient, such as nitrogen is added to a lake or stream the water becomes *enriched* and further growth of algae and other plants ensues. This process of enriching the water is called *eutrophication.* The resulting excess plant growth can cause taste and odor problems in lakes used for drinking water, can cause nuisance problems for users of the water body, or can adversely affect fish and other aquatic animals. Concerns about excess nitrogen or phosphorus in lakes and coastal waters are often associated with sewage discharges. Concentrations of nitrate should always be expressed as elemental nitrogen. Thus nitrate is expressed as nitrate nitrogen (NO_3-N) in milligrams per liter (that is, 14g of nitrogen per mole of NO_3^-), and never as NO_3 (that is 62g per mole of NO_3^-). Most natural waters have nitrate levels under 1mg/L nitrate nitrogen, but concentrations up to 10mg/L nitrate nitrogen are found in some areas.

The Importance of Measurements

The condition of the Earth's many surface waters is valuable for ecological preservation and maintenance of streams, rivers, lakes and coastal waters. Knowledge of local trends in water quality is based on sampling at selected sites. Before changes in water quality can be assessed, reliable information must be gathered on current conditions at sites. When changes are already underway, comparisons of affected and unaffected areas can help us understand what is happening.

Measures of dissolved oxygen and pH directly indicate how hospitable a body of water is to aquatic life. It is interesting to follow the annual cycle of dissolved oxygen, alkalinity and pH, and to make comparisons between different water bodies. We can ask questions, such as whether dissolved oxygen levels are always at the maximum allowed by the temperature of the water, or are they depressed during part of the year? If they are low, we want to know the cause. We can see if pH becomes depressed right after a rain or when there is a lot of snowmelt running off into the lake or stream. If we do find a depression in pH, we would expect that this water had a low level of alkalinity. In fact, we should expect that waters with a low alkalinity would have a depression in pH following rainfall or snowmelt. But we must take the measurement to confirm whether or not that really happens. Within an enclosed system, such as a cave or cavern, we can ask -- Does human impact occur more often at some areas than others? Can we identify those particular problem areas? Which type of human impact is most prevalent? Is human impact seasonal? Is there a correlation in natural and human impact on bodies of water?

Students should make the suite of measurements with two societal goals in mind. First, we want to develop a better understanding of our local land and water resources. This knowledge can help us make more intelligent decisions about how we use, manage and enjoy the resources. Second, we want to assess the extent to which human activities are affecting the quality of our water and thus affecting how we will be able to use it in the future.